Diagonally Layered Multi-Antenna Transmission for Frequency Selective Channels

TECHNICAL FIELD

The present invention relates to mobile cellular communication networks employing multiple access schemes and more exactly to a method of transmitting multiple data streams (layers) from multiple transmitting antennas.

BACKGROUND

Mobile cellular communication networks employ multiple access schemes in which inter-symbol interference (ISI) needs to be combated through equalisation. Obvious embodiments are the TDMA (Time Division Multiple Access) based GSM (Global System for Mobile Telecommunications), now evolving into the enhanced data rates for GSM, GSM/EDGE Radio Access Network (GERAN), and the TD-CDMA (Time Division Code Division Multiple Access) based UTRA-TDD (UMTS Terrestrial Radio Access Time Division Duplex) network. The description below uses GSM terminology to exemplify the invention. The invention particularly relates to encoding and decoding of multi-layered signals transmitted over a Multiple-Input Multiple-Output (MIMO) frequency selective channel.

Spectrum has become a limited and expensive resource in mobile cellular radio communication networks. Therefore, much attention is given to improving the spectral efficiency. One method of increasing capacity without an increased bandwidth is to exploit multiple antennas at both transmitter and receiver. The channel between transmitter and receiver is a MIMO channel. Such a MIMO channel does offer a much greater channel capacity compared to a channel with one transmitting and one receiving antenna [1].

There exist several proposed techniques in which the MIMO channel is exploited to increase capacity. Some of the more attractive techniques for exploiting the MIMO channel are techniques in which data is divided into

separate layers being transmitted simultaneously, and where each layer may in the receiver be demodulated and decoded separately from all other layers. A layered space-time architecture for multi-element antenna arrays proposed by G. J. Foschini [2] is now often referred to as BLAST (Bell-Labs Layered Space-Time Architecture), designed for systems with flat fading channels. The BLAST method can be divided into two sub-classes: Diagonal BLAST (D-BLAST) [3] and Vertical BLAST (V-BLAST) [4], which are shown in Figure 1 for a transmission system with two transmit antennas. In another paper by Foschini et al, [5] it was mentioned that "with diagonal layering, some space-time is wasted at the start and end of each burst." However this does not relate to avoiding problems with ISI when changing transmit antenna for the different layers. Instead they conclude that in the beginning and end of a radio burst there will be a decreased capacity with the coding algorithm and the receiver algorithm they apply.

In D-BLAST a stream of data is de-multiplexed into several sub-streams, or layers of data, each of which may be encoded and mapped onto symbols independently. At a given time each layer is transmitted by a separate antenna. In the transmitter the antenna to which a layer is coupled changes at regular intervals. A position in a burst, where a layer changes transmit antenna, will for simplicity be referred to as a border between two layers. The transmitting antenna of a layer is switched in a cyclic fashion so that each layer is in total transmitted an equal length of time from all antennas. The layers could switch antennas as slowly as is shown in Figure 1, or as fast as every symbol. This serves to ensure that none of the layers experiences the worst transmission path for a complete burst. If one of the transmission paths is lost due to fading it could still be possible, thanks to the transmission from multiple antennas, to recover the layer through use of an error correcting channel code such as e.g. a convolutional code.

Also for V-BLAST a stream of data is de-multiplexed into several layers of data, each of which may be encoded and modulated independently. As opposed to D-BLAST, each layer is associated to one transmit antenna for

the complete burst. This means that, if one transmit antenna is lost due to e.g. fading, a complete layer transmitted from that antenna will be lost.

In the receiver a staged demodulation and decoding is typically considered, where each layer is demodulated and decoded separately. In practice this requires multiple antennas also for the receiver. Typically the number of receive antennas should be at least as large as the number of transmit antennas. This allows the receiver to suppress all layers, except for the desired layer, from the received signals. After a layer has been demodulated and decoded it is cancelled from the received signal. Alternatively, a layer may be cancelled from the received signal directly after demodulation and before decoding. This may be preferable, either if a code with high code rate has been used, or if a layer has been encoded over several transmission bursts, in which case the receiver would need to receive all bursts, over which the layers have been encoded, before demodulation and decoding is to begin.

In a recent US Patent [6] a receiver algorithm is described where multiple receiver antennas are utilised to suppress co-channel interference (CCI) and then using a "Viterbi-equalizer" to take care of ISI. However this only relates to a specific receiver algorithm but not any method for the transmission.

For V-BLAST performance is improved if the receiver determines which layer had the best transmission quality, and then demodulates and decodes, alternatively only demodulates, that layer first.

THE PROBLEM TO BE SOLVED

For mobile cellular radio communication networks, which require equalisation in order to combat inter-symbol interference (ISI), e.g. GERAN, problems arise for multi-antenna transmission systems which switch transmit antenna within a burst, e.g. D-BLAST.

In Figure 2 the propagation paths for a transmission system with two transmit and two receive antennas are shown. A symbol sequence transmitted from transmit antenna Tx_1 is received by receive antenna Rx_1 through the channel h_{11} and by Rx_2 through h_{12}. Similarly, a symbol sequence transmitted from Tx_2 reaches Rx_1 through h_{21} and Rx_2 through h_{22}. If the channels h_{11}, h_{12}, h_{21} and h_{22} are time-dispersive, the received signals will be corrupted by ISI. To combat the ISI requires equalisation.

For multi-antenna transmission systems which transmit layers from several transmit antennas, the symbols in a layer closest to the border to another layer are corrupted by ISI, not only from symbols in the same layer, but also from symbols in the adjacent layer. The ISI from an adjacent layer will for simplicity be labelled inter-layer inter-symbol interference (inter-layer ISI). This problem is illustrated in Figure 3 for two-layered D-BLAST transmitted through 3-tap channels (channels with a memory of two symbols). Two symbols to either side of the border between the two layers are corrupted by inter-layer ISI. Areas in Figure 3 marked as "overlap between layers" indicate symbols affected by inter-layer inter-symbol interference. This makes it difficult for a receiver which successively demodulates and decodes the layers, since for good equaliser performance, the symbols from the second layer also need to be considered when the first layer is equalised.

For a V-BLAST like solution ISI causes no particular problem since each layer is transmitted from the same transmit antenna for a complete burst. However, V-BLAST like transmission schemes do not offer any transmit diversity, since each layer is transmitted from only one antenna.

SUMMARY OF THE INVENTION

A method and a system for avoiding inter-layer inter-symbol interference are disclosed. The method and system utilise diagonally layered multi-antenna transmission. Known symbols are inserted at the borders between different layers to avoid inter-layer inter-symbol interference. The system relies on a new method to transmit multiple data-streams (layers). The invention

describes a method for transmitting data-streams over multiple antennas in an efficient, cost effective and powerful way when having frequency selective channels. By using the present method problems with inter-layer ISI between different data-streams can be avoided when changing transmit antenna for the data-streams. The invention utilises diagonal layered multi-antenna transmission causing no ISI between different layers.

The known symbols, which are inserted at the borders between different layers may be used for purposes such as for instance channel estimation. The known symbols may constitute a training sequence. Typically for a system having a first and a second transmit antenna, and a burst structure containing a training sequence in the middle of a burst and with data fields to either side of the training sequence, such as e.g. GSM and UTRA/TDD do, this burst structure can be exploited for the diagonal layering. On the first transmit antenna a layer one is transmitted in the left data field and a layer two is transmitted in the right data field, while on the second antenna the layer two is transmitted in the left data field and the layer one is transmitted in the right data field thereby separating the two layers by the known training sequence which avoids inter-layer ISI, without having to reduce the number of data symbols that are transmitted.

SHORT DESCRIPTION OF THE DRAWINGS

The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken together with the accompanying drawings, in which:

FIG. 1 illustrates D-BLAST and V-BLAST multi-antenna transmission schemes for two transmit antennas wherein data is divided into two independent layers and for D-BLAST an equal number of symbols is transmitted from each antenna, while for V-BLAST each layer is transmitted from only one antenna;

FIG. 2 illustrates propagation paths for a system having two transmit and two receive antennas;

FIG. 3 illustrates D-BLAST for channels with inter-symbol interference where the symbols of each layer affected by inter-layer ISI are marked and for a 3-tap channel, two symbols to either side of the border are affected;

FIG. 4 illustrates a diagonally layered 2-antenna transmission scheme suited for channels with inter-symbol interference whereby known symbols are inserted at the border between the two layers in order to avoid inter-layer ISI and for 3-tap channels two known symbols for each transmit antenna is sufficient;

FIG. 5 illustrates GSM radio burst;

FIG. 6 shows a 4-antenna transmission where the transmit antennas are divided into two sub-sets, with two transmit antennas within each sub-set and diagonal layering is employed within each sub-set;

FIG. 7 illustrates an exemplary base-band block diagram for the transmitter; and

FIG. 8 illustrates in a diagram the main steps according to the present method.

DETAILED DESCRIPTION

A diagonally layered multi-antenna transmission scheme like D-BLAST has a greater capacity potential than a V-BLAST like scheme due to transmission from several transmit antennas for each layer, as opposed to transmission from only one antenna for each layer. This invention then allows diagonally layered multi-antenna transmission schemes to be employed also for communication networks suffering from ISI, without causing inter-layer ISI.

The inter-layer ISI can be avoided by inserting known symbols into the sequence transmitted from each antenna at every border between different layers (see Figure 4). If the number of known symbols is at least as large as the channel memory (the number of channel taps minus one) there will be no ISI between different layers. This means that the amount of user data that can be transmitted will be reduced, since the number of data symbols is reduced. However, the known symbols could be used also for other purposes such as e.g. channel estimation and synchronisation.

For the special case of two transmit antennas the burst structure employed in e.g. GSM and UTRA/TDD can be exploited. In those networks a burst consists of two fields of data separated by a training sequence of known symbols used for e.g. channel estimation (see Figure 5). For this case, from the first transmit antenna the first layer is transmitted in the data field to the left of the training sequence, and the second layer is transmitted in the data field to the right of the training sequence. From the other transmit antenna the second layer is transmitted in the left data field and the first layer in the right field. As the training sequence is longer than the channel impulse responses there will be no inter-layer ISI. By exploiting an existing burst structure inter-layer ISI can be avoided for a diagonally layered multi-antenna transmission scheme without having to reduce the number of data symbols that are transmitted.

In a document by Lindskog and Paulraj [7] they present a space-time block code for two transmit antennas that uses an approach similar to the one considered in this invention. As code block for the space-time block-code, they define a radio burst, where the left data field is one symbol in the space-time block-code and the right data field the second space-time block-coding symbol. These two space-time block-coding symbols are transmitted from both transmit antennas and are separated in time by the training sequence. However, compared to the present invention where multiple layers of independent data provides increased bit rates, the method of Lindskog

and Paulraj transmits the same data on both transmit antennas, and therefore does not offer increased bit rates, only increased diversity. Further, by using the training sequence to separate the space-time block coding symbols, orthogonality within the space-time code block is ensured, which enables a low complexity decoding of the space-time code, whereas this invention allows separate detection of each of the multiple layers.

For diagonally layered multi-antenna transmission in case of ISI with more than two transmit antennas, layering over all antennas may require transmission of quite a lot of known symbols. An alternative approach would be to divide both the transmit antennas and the layers into sub-sets, each sub-set containing a number of transmit antennas and the corresponding sub-set of layers containing a number of layers equal to the number of transmit antennas. Within each sub-set the layers are layered diagonally across the transmit antennas. This is shown for the special case of two antennas within a sub-set in Figure 4, where the two layers within a subset are separated by known symbols. However, there is no layering across antennas belonging to different sub-sets. This is shown in Figure 6 for a 4-antenna transmission scheme. In a further application it would additionally be possible to use more than two antennas for a sub-set, even if we for simplicity here consider embodiments having just two antennas for a sub-set. It would also be possible to consider having different number of antennas, and thus also different number of layers, in different sub-sets. The division of antennas and layers into sub-sets could be changed dynamically as often as every radio burst, and different sub-set division could be allowed for different users.

Using the diagonally layered multi-antenna transmission scheme proposed in this invention inter-symbol interference (ISI) between different layers is avoided. This allows the receiver to demodulate and decode the layers sequentially. A complete layer is demodulated (including equalisation) and decoded, before it is cancelled from the received signal. Thereafter the next layer is demodulated and decoded, and so forth. Using diagonal layering

without consideration of ISI between layers the receiver will not be able to demodulate and decode a complete layer before cancelling it. In this case the complete sequence of symbols transmitted from one antenna would have to be demodulated and cancelled. This means that only parts of each layer is demodulated before cancellation, which is performed before decoding. Being able to perform decoding before cancellation reduces the amount of errors, and thus the effect of error propagation, which may occur when a cancelled layer contains estimation errors.

The alternative is to use a V-BLAST like multi-antenna transmission scheme where there is no risk of inter-layer ISI. However, transmit diversity, which improves performance, in particular for layers onto which low rate channel codes have been applied, is not provided with such a scheme. Further, for good performance in a V-BLAST like multi-antenna transmission scheme it is important to determine which layer has experienced the best transmission quality, and to begin with this layer. This is not necessary for the diagonally layered multi-antenna transmission scheme, since all layers are transmitted equally over all transmit antennas. This means that additional gains could be achieved if different code rates are used for the different layers. The layer being demodulated and decoded first could be given a lower code rate, since this layer gains the least from diversity. By improving this layer, performance of subsequent layers may also improve. However, it should be pointed out, that the method will not be limited to any particular receiver algorithm.

Figure 7 illustrates in a simplified base-band block diagram an exemplary illustrative embodiment of a diagonally layered multi-antenna transmission scheme, where a data stream is de-multiplexed into two individual layers, each of which is independently coded, interleaved and mapped onto symbols. Thereafter the layers are mapped onto the two transmit antennas according to the diagonal layering method.

Figure 8 illustrates in a diagram the main steps for forming a diagonally layered multi-antenna transmission according to the present method disclosed.

It will be understood by those skilled in the art that various modifications and changes may be made to the present invention without departing from the spirit and the scope thereof, which is defined by the appended claims.

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